Design & Engineering Services

LED Street Lighting Assessment

ET 09.01 Report

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Southern California Edison's Design & Engineering Services (D&ES) group is responsible for this project. It was developed as part of Southern California Edison's Emerging Technology program under internal project number ET 09.01. D&ES project manager Teren Abear conducted this technology evaluation with overall guidance and management from Alok Singh and Anthony Hernandez. For more information on this project, contact *teren.abear@sce.com*.

Disclaimer

ABBREVIATIONS AND ACRONYMS

AC	Alternate Current
CCT	Correlated Color Temperature
CRI	Color Rending Index
CZ	Climate Zones
GHG	green house gas
GSM	Global System for Mobile Communications
HPS	High Pressure Sodium
Hz	Hertz
IES	Illumination Engineering Society
IESNA	Illumination Engineering Society of North America
ILC	Integrated Lighting Concepts
kWh	kiloWatt hours
LDD	Lumen Dirt Depreciation
LED	Light-emitting Diode
LLD	Light Loss Depreciation
LLF	Light Loss Factor
LPS	Low Pressure Sodium
Rms	Root Mean Square
V	Volts

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EXECUTIVE SUMMARY

The goal of this project is to provide an in-depth analysis of the feasibility of light-emitting diode (LED) technology that can potentially replace high pressure sodium (HPS) lamps in street lighting applications, specifically cobrahead-style luminaires. This analysis aids in identifying performance, energy savings and maintenance cost reduction potential of LED luminaires in comparison to HPS cobraheads. The results of this assessment will provide a foundation for understanding market potential, testing protocol and stakeholder preference.

This project builds upon various studies conducted on LED technologies throughout the industry. Because LED technology is so dynamic, study results often fall behind the current state of available products and performance. Many studies often include multiple variables such as numerous manufacturers, distribution, color and other technologies all within the same assessment. Including multiple variables can often make it difficult to analyze LED technologies performance benefits over HPS. Perception studies are also being conducted. Review of some of these studies has provided valuable information on other demographics. In order to understand SCE's wide range of demographics a parallel perception study is being conducted in coordination with this project. The perception study is based upon surveying residents in and around the LED Street Light project test sites with respect the perceived performance of the luminaires.

Southern California Edison's (SCE) service territory includes a wide range of climate zones from cool coastal climates to hot desert climates. Many of the existing studies within the industry were conducted in cooler climates only. This project focuses on the performance, and ultimately, the efficiency potential of LED technology throughout a wide range of extreme temperatures. Also, unlike the other Investor Owned Utilities (IOU) in the state, SCE owns and operates approximately 80% of the street lights, where the other 20% are owned and operated by various local governments. When considering energy saving incentives, the market size for those cities is around 200,000.

The main advantage of LED technology, as reported in the literature, is its energy efficiency, higher efficacy, longer measure life, and improved durability to name a few, and as the technology continues to evolve there may be additional benefits. The LED luminaires tested in this project show a wide range of energy savings potential, with energy consumption a function of their performance. However, when replacing an existing luminaire on a one-for-one basis there are several parameters that should be considered. The replacement luminaire should meet or exceed the performance of the incumbent technology including overall light output, distribution and quality. This project takes a deeper look into the major aspects regarding the feasibility of luminaire replacement for the goal of saving energy and operating costs.

There are three main stages to this project:

- Simulations
- Laboratory Analysis
- Field Testing.

The performance testing is aimed at determining not only photometric performance but energy savings potential as well. Power consumption is measured and monitored throughout the laboratory analysis and field testing.

Simulation - The simulation stage of the project is designed as a filter to narrow the amount of fixtures that will move on to the next stage of the project. This simulation entails modeling a typical street lighting scenario using lighting simulation software to show photometric performance. Based upon the simulation results four fixtures were selected to proceed to the laboratory analysis stage.

Laboratory analysis - There are two parts to the laboratory analysis:

- luminaire performance with respect to light output, and
- quality of light.

Laboratory Analysis - Temperature dependency analysis of the laboratory data indicates that an increase in temperature from 40°F 100°F results in a light output decrease of approximately 8% to 9%. This can be a significant amount when taking into consideration the defined end-of-life of an LED luminaire (L_{70}) - that is 30% of its initial output.

The quality of light tests verified claims on the performance of the luminaires including photometrics and power. The results of this testing helped to determine which of the four luminaires would be field tested.

Field testing - The field testing is intended to determine the performance of LED luminaires in a sampling of the broad range of climate zones within SCE's service territory. Four cities were chosen based upon their climate significance; coastal, metropolitan, central valley and desert. This demographic represents the coolest and warmest climates as well as a couple of moderate climate zones.

Project findings from the simulations show that LED luminaires are able to match the minimum illuminances set by the HPS baseline and although uniformity improved, the average and maximum illuminances are less than that of the HPS.

The field measurements helped to confirm the simulation data as the observed values were along the lines of what was expected. Although LED luminaires show significant energy reductions of approximately 40% over HPS and have better uniformity while meeting the minimums, there was a reduction in average illuminance.

The total cost of ownership comparison showed the cost savings potential for customer-owned equipment. When considering the equipment and installation costs, the customer-owned costs show that LED is close to matching that of HPS, even at a short operating life of 11.4 years. This also assumes that the LED luminaire operates without any maintenance for that same period of time. The tariff structure is another factor to consider as the energy costs make up approximately 50% of the LS-2 customer-owned tariff.

Although there are energy savings of 40%, the light output of the tested LED luminaires do not meet the average illuminance that the HPS provide. While the definition of "equivalent luminaire" has multiple definitions, average illuminance is a key factor. By using LED luminaires with increased light output, meeting the HPS luminaires performance is possible, however the energy savings is reduced and luminaire costs increase. These factors affect the overall savings that are analyzed using lifecycle cost. The lifecycle cost takes into account all related costs to operate and maintain a luminaire throughout a given time period.

There are many standards and recommended practices within the industry that are currently in flux. Increased involvement within the industry will be beneficial in steering the technology in the right direction. LED technologies are advancing very rapidly and as a result, the industry is trying to keep up. Further evaluation of newer products will help to better understand the industry trends and how fast the technology is advancing.

LED technology continues to emerge with more luminaires coming to market that increase efficiency and lower costs. Since each application and/or customer is different, the current numbers may not show financial benefits now, however all trends indicate that the technology is advancing and costs are reducing. In the future LED Street Light Luminaires have the potential to become the newest energy-efficient and cost-effective option for roadway lighting.

RECOMMENDATIONS

- Conduct further scaled field testing in the areas and applications where they will be used (i.e., specific climate zones).
- Additional laboratory testing with regards to thermal and photometric performance, ease of use, aesthetics and durability of the luminaire housings.
- Continued involvement in the development of standards that address the dynamics of this technology.
- Conduct expanded market analysis of available LED streetlight technology and associated luminaire and lifecycle costs.
- Continue to monitor the industry for new emerging technologies beyond LEDs.

INTRODUCTION

Light-emitting diode (LED) technology, also referred to as solid-state lighting (SSL), has experienced a very rapid advancement within the past few years. The technology has existed for over 40 years and was typically used in small indicator lamp applications and only available in a limited range of colors. Fairly recent developments in the technology allow for a much larger range of available colors that led to the ability to produce white light. This advancement, along with continuing increases in performance, is leading the technology toward many other lighting applications.

The consumer market has taken notice of the advancements of this technology and there is an increasing demand, mainly because of the potential energy savings that this technology offered. Other studies of the technology in different applications yield promising results as well as indicate current short comings. This study aims to evaluate the state of LED technology and its current viability for use in Street Lighting applications.

MARKET DESCRIPTION

Street lighting is one of the earliest applications for electric lighting technologies that were previously gas powered. Since the transition from gas, electric lighting technology for street lighting has evolved from incandescent to mercury vapor to high pressure sodium (HPS) and low pressure sodium (LPS) lamps. HPS lamps have been a standard throughout the United States since the 1980s. There are newer technologies that may have some potential for improvements on light output, efficiency and maintenance that include fluorescent induction technology, LEDs, Plasma, HID and Organic LEDs.

Within the last few years LED technology has seen significant and rapid advances in performance. This speed of advancement was not seen in electric lighting before. The rapid advancement is pushing this technology into more and more applications while its energy savings and green house gas (GHG) reduction potential has created a stronger market demand.

Although rapid advancement can be a benefit, it can also be a challenge to properly assess the state of the technology. Manufacturers of LED chips are making advancements every few months with luminaires continuously evolving. Increasing numbers of luminaires are arriving in the market at a faster pace. This makes it difficult to conduct any long-term testing. In addition, standards for the technology and its applications are still catching up to the advancements. This adds a further challenge on using proper metrics for comparisons and makes the analysis for any application dependant on not just the current and existing metrics for that specific application, but for the technology as well. In the case of street lighting the industry is currently working on updates to lighting standards and recommended practices. These updates are at least months, if not years away from adoption.

The street lighting market is unique in that there are only a few types of customers, and while regarded as an off-peak load, it is a significant portion of that load. Cities, municipalities and government institutions are the ultimate customers with the general public as the end-users. The breakdown of street light ownership boils down to two parties, electric utility or customer.

Within Southern California Edison's (SCE's) service territory there are three different types of rates or tariffs specific for street lighting. The tariffs are:

- LS-1[1]: Owned and operated by SCE and charged to customers at a flat rate,
- LS-2[1]: Owned and operated by the customer who is charged a flat rate by SCE, and
- LS-3[1]: Owned and operated by the customer and charged at a metered rate.

There are nearly a million street lights within SCE's service territory and among those about 80% are LS-1 luminaires and 20% are LS-2 luminaires. The LS-3 luminaires are difficult to estimate since they are not tracked by pole because they are behind meters.

OBJECTIVES

The main objective of this project is to take an initial and in-depth look at LED technology for Street Lighting applications as it applies to customer- owned and operated luminaires within SCE's range of climate zones. This analysis focuses on the performance of LED street lighting luminaires as compared to the existing standard of HPS cobrahead luminaires with respect to photometric performance and energy savings potential.

The first part of the project involves a computer simulation to compare the current HPS baseline to several LED luminaires. The simulation process filters the product data to determine which luminaires qualify to advance to the laboratory testing phase. The laboratory testing further tests the luminaires as well as helps to verify manufacturer-provided test data. The thermal testing of the luminaires allows for a controlled environment in which the effects of ambient temperature on the light output can be assessed. Based upon the simulations and laboratory testing two manufacturers were selected to provide luminaires for the next phase of testing – the field tests. The field tests are designed to determine a real-world comparison of the HPS and LED luminaires. In addition to the actual spot measurements the actual field test locations are modeled in the simulation software to compare the accuracies of the modeling.

The results from this project focus on determining the feasibility of replacing HPS cobraheads with LED luminaires for the customer-owned luminaires on the LS-2 and LS-3 tariff. The performance data, however, applies to all street light luminaires. This data serves as a foundation for further testing as the technology progresses.

Note that this assessment focuses specifically on cobrahead-style street light fixtures only.

METHODOLOGY AND INSTRUMENTATION

INITIAL SIMULATIONS

There are many luminaires available in the market for Street Lighting applications with more luminaires entering the market almost daily. This initial investigation used AGI-32, an industry recognized standard software for lighting simulations. This software is used to compare the existing HPS baseline with available LED luminaires in order to narrow the field of luminaires for further testing.

MODELING DESIGN PARAMETERS

100W HPS COBRAHEADS

- Baseline model with 30-foot mounting height. Two layout configurations; one side loaded with 100 feet between luminaires and staggered spacing with 150 feet between luminaires.
- LDD of .85 (.83 - .88 at 18,000 hours [4 years] per IESNA documentation)
- LLD of .75 (estimated light loss of 25% at 18,000 – 19,000 hours [4 years] 80% lamp life)
- LLF of .64 (LLF based on combined LDD and LLD with other factors as baseline from IES photometry files)

LED COBRAHEADS

- Alternate designs with 30-foot mounting height. Two layout configurations; one side loaded with 100 feet between luminaires and staggered spacing with 150 feet between luminaires.
- LDD of .90 (.89 - .91 at 50,000 hours [12 years] per ILC estimate)
- LLD of .70 (estimated light loss of 30% at 50,000 hours operation [useable life])
- LLF of .63 (LLF based on combined LDD and LLD with other factors as baseline from IES photometry files)

LABORATORY EVALUATIONS

The laboratory evaluations consist of a two-part test. The first test measures the photometric and power characteristics of the luminaires while the second test measures the dependency of the luminaires light output with respect to temperature.

Testing was conducted at SCE's Technology Test Centers (TTC). See Appendix A – Technology Test Centers for additional information on these facilities.

PHOTOMETRIC TESTING

The photometric testing was conducted using an integrating sphere described in the Equipment section below. Figure 1 shows the mounting system in the integrating sphere.

FIGURE 1. LUMINAIRE SETUP IN INTEGRATING SPHERE

PROCEDURE

Testing was performed in accordance with the "IES Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products" (IES LM-79-08), excluding section "2.2 Air Temperature". LM-79-08 requires ambient air temperatures be maintained at 25 centigrade (77°F), plus or minus 1 centigrade, as measured 1 meter from the product and at the same height as the product. In actual testing, ambient temperature was not maintained at 25 centigrade, but was monitored throughout the test.

LIGHT OUTPUT

Light output is the measure of light that a source provides in lumens. Light output data was obtained from the integrating sphere test discussed in the Equipment section, below.

COLOR RENDERING INDEX

Color rending index (CRI) is a quantitative measure that describes how well a light source renders color compared to a reference light source of similar color temperature. This index is scaled from 0-100.

The color quality, measured as CRI, affects visual perception. The CRI is directly related to the colors or spectral characteristics that the lamp produces. CRI data is obtained from the integrating sphere test discussed in the Lab Equipment section, below.

CORRELATED COLOR TEMPERATURE

Correlated color temperature (CCT) indicates whether a white light source appears more yellow/gold or blue, in terms of the range of available shades of white. CCT is derived by a theoretical object in physics, referred to as a "black body," that absorbs all electromagnetic radiation. When heated to high temperatures this object emits different colors of light based on the exact temperature. Hence, the CCT of a light source is the temperature (in Kelvin) at which the heated black body matches the color of the light source in question. The "hotter" (higher Kelvin) the more blue in appearance, the "cooler" (lower Kelvin) the more red in appearance. CCT data is obtained from the integrating sphere test, discussed below, and is compared to the manufacturer's CCT ratings.

CONNECTED LOAD

Power requirements for all test cases are determined by measuring current and voltage. Measurements for both are taken between the driver and power source to understand alternate current (AC) power. This information is used to understand demand (kW) savings of the measure cases when compared to the baseline cases.

EFFICACY

An important indication of overall lamp performance is efficacy. This value, in lumens per watt (lm/W), is a measure of light output over power input. A higher efficacy lamp provides more lumens of light output per watt than a lower one. Though LED wattage may be lower than their fluorescent counterpart, it must do so while providing the same amount of light. A lamp with a higher efficacy has the most energy savings potential.

TEMPERATURE-DEPENDENCY TESTING

The controlled environment testing consists of measuring the relative light output and electrical demand for each fixture under varying temperatures.

PROCEDURE

- First, the room is stabilized at a given temperature within 1°F, at the following temperatures: 40°F, 50°F, 60°F, 70°F, 80°F, 90°F, and 100°F.
- Second, the fixture is allowed to reach stability as determined by the variation in Equation 1 (adapted from IES LM-79-08 as described in the Equipment section under Integrating Sphere).

EQUATION 1. VARIATION EQUATION

$$\left(\frac{high_{last3} - low_{last3}}{latest}\right)100 < 0.5$$

Where:

Readings are taken at 15-minute intervals.

$high_{last3}$ = highest value from last three consecutive readings

low_{last3} = lowest value from last three consecutive readings latest = latest reading

If the equation is true for both light and electrical demand, the fixture is assumed stable and final readings are taken for that temperature.

- Third, the process is repeated for the next temperature in the table.

EQUIPMENT

Several pieces of equipment are used throughout the assessment and each piece is described in the following sections. For additional information and technical specifications see Appendix B – Equipment.

INTEGRATING SPHERE

The integrating sphere measures the total light output of a light source. This can be a lamp or a complete luminaire. The tested light source is placed in the center of the integrating sphere. At one side of the sphere is a light meter that measures the light output from the light source. A baffle is directly between the source and the light meter to prevent the meter from seeing any direct light from the source. This equipment is used to measure the light output of a light source, the CRI, and CCT. The temperature is regulated to approximately 77°F. Measurements are taken every 15 minutes until three consecutive measurements are within 0.5% of each other.

The entire inside of the sphere (including the baffle and mounting for the lamps) is coated with a highly reflective white paint that reflects all wavelengths equally. This allows for accurate measurements. The calibrated power supply is connected to the lamp wiring on the outside of the sphere. Readings from the optical sensor are processed with the integrated software and displayed on the monitor.

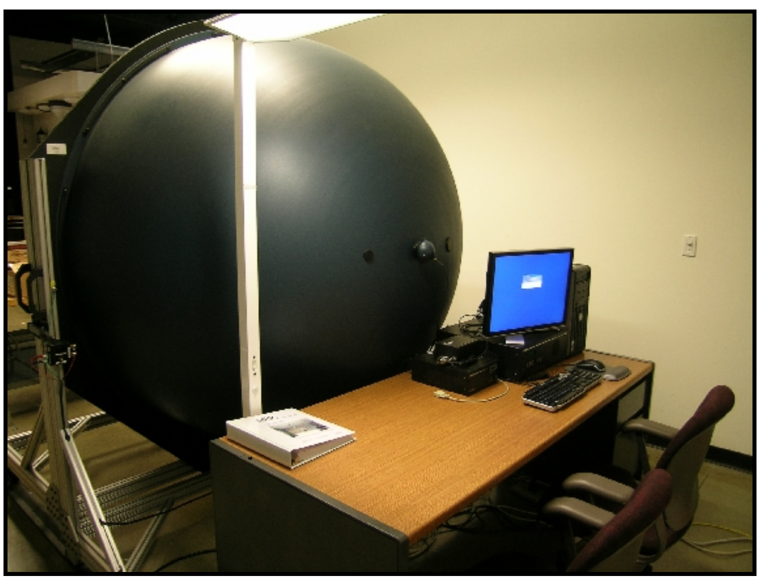


FIGURE 2. INTEGRATING SPHERE

LIGHT LOGGING SYSTEM

Illuminance (lux) is measured with three LI-COR LI-210 photometric sensors connected to a LI-COR LI-1400 handheld data logger. The sensors are positioned directly below the fixture on the leg of a pole stand.

CONTROLLED ENVIRONMENT ROOM

Each fixture is mounted in a controlled environment room to a custom pole stand approximately 5-feet high. The pole stand is located away from the conditioned air discharge grill, where air movement is minimized and temperatures are more stable. After a fixture and sensors are installed, the room is left undisturbed until all temperature readings are completed for that fixture. Only the fixture, pole stand, thermocouples, and photometric sensors are located in the controlled environment room. The power supply and logging equipment are located outside the room in normal room temperature.

TEMPERATURE LOGGING SYSTEM

Temperature (°F) is measured with four redundant thermocouples positioned within 1 meter of the fixture and at the same height as the fixture. Two more thermocouples are thermally bonded to the fixture's heat sink (whether externally accessible or internal to the housing) using thermal paste and aluminum tape. All six thermocouples are monitored and logged using a National Instruments data acquisition system installed for the controlled environment room. Readings are logged every 1 minute. Figure 3 shows the temperature logging system where the thermocouples are setup at 1 meter from the fixture.

FIGURE 3. TEMPERATURE LOGGING SYSTEM SENSOR SETUP

Regulated Power Supply

Regulated power is supplied to each luminaire by a Tenma 72-7675 AC power source set at 120V rms and 60 Hz.

Power Quality Analyzer

Voltage (V rms), current (A), power (W), frequency (Hz), power factor (PF), and current THD (%) are measured with a Fluke 435 power quality analyzer with two Fluke i5s AC current clamps. Readings are logged every 5 seconds, and manually monitored every 15 minutes for stability during the controlled environment room testing.

Figure 4 shows the monitoring test equipment for the controlled environment room test set up outside the controlled environment room.

Figure 4. Monitoring Test Equipment - Regulated Power Supply, Power Quality Analyzer and Light Logging System

Field Assessments

Field assessments include spot measurements of the baseline HPS compared with the LED measure. These assessments map out a grid on the street/sidewalk areas as also done in the initial simulations. This is a real-world test that is compared to computer simulations that use the exact measurements of the streets and luminaires placements.

In addition to spot measurements, logging equipment is installed to monitor ambient temperature, relative humidity, internal luminaire (driver cavity) temperatures, and power.

EQUIPMENT

REMOTE MONITORING SYSTEM

The HOBO U30-GSM Remote Monitoring System from Onset Computer Corporation was used to remotely log several field assessment data points. The system allows for a flexible array of sensors including temperature and energy usage. Table 1 show the standard measurements used in the assessments.

TABLE 1. REMOTE MONITORING SYSTEM MEASUREMENTS

MEASUREMENT
Internal Temperature 1
Internal Temperature 2
Ambient Temperature, Relative Humidity, Dew Point
Energy Usage (kWh)
RMS Voltage
RMS Current

Figure 5 shows the field logging equipment installed on the street light pole. The system is self-powered by an internal battery kept charged with a photovoltaic panel. Data is remotely downloaded via a Global System for Mobile Communications (GSM) cellular connection.

FIGURE 5. FIELD LOGGING EQUIPMENT

The WattNode[2] device measures energy consumption or kilowatt hours (kWh). Equation 2 is used to extract power or kilowatts (kW) from the data.

EQUATION 2. KWH TO KW EQUATION

$$Power(W) = \frac{VAC \cdot PpPO \cdot CTamps \cdot PulseCount}{FSHz \cdot 3600}$$

Where:

Values defined in WattNode Installation and Operation Manual.[3]

VAC = nominal line voltage

PpPO = 3

CTamps = 2.5

PulseCount = measured

FSHz = 4

INITIAL SIMULATION RESULTS

The simulations were conducted by Integrated Lighting Concepts based upon assumed typical street lighting layouts and IES files provided from the several manufacturers.

MODELING DATA

The tables in this section show the rated lumen output versus power as well as simulated values for average lux, uniformity and rated wattage. There are two types of lamp styles for the HPS technology, BD-17 and ED-23. These styles may affect the geometry of the lamp and therefore its performance in a standard cobrahead luminaire.

Note that LEDs C and D were omitted from data tables since the IES files obtained were not for a complete luminaire, but rather individual modules that made up a luminaire for that manufacturer. This does not appropriately reflect a proper replacement as the thermal management components are not considered in the model.

LUMEN OUTPUT POWER

The total lumen output for LED and HPS luminaires cannot be compared directly due to how light is distributed by the luminaire. Table 2, below, shows the rated lumen outputs as well as power consumed.

TABLE 2. LUMEN OUTPUT AND POWER

LUMINAIRE	LUMINAIRE LIGHT OUTPUT (LUMENS)	RATED POWER (WATTS)	CALCULATED EFFICACY (LUMENS/WATT)
Luminaire A*	3031	53.6	57
Luminaire B	3389	49.1	69
Luminaire E	2133	48.2	44
Luminaire F	N/A†	70	N/A††
Luminaire G	5110	75	68
Luminaire H	4856	75	65

*Luminaire A newer generation with higher efficacy and higher average LUX was implemented in the field study.

†Luminaire F lumen output not listed in IES file.

Note that the lumen output values seem to vary with the luminaires that were recommended by the manufacturer to replace a 100W HPS luminaire. The simulations below indicate the actual light delivered to the roadway.

INLINE PLACEMENT

Inline placement is where the street light poles are located on one side of the street as shown in Figure 6, below.

FIGURE 6. INLINE LUMINAIRES

Table 3 shows the simulation results for the 100-foot inline spacing model using 600 data points. Note that the power values represent manufacturer ratings.

TABLE 3. INLINE PLACEMENT – 100-FOOT SPACING

LUMINAIRE	AVERAGE ILLUMINANCE (LUX)	MAXIMUM ILLUMINANCE (LUX)	MINIMUM ILLUMINANCE (LUX)	UNIFORMITY RATIO (AVG/MIN)	UNIFORMITY RATIO (MAX/MIN)	POWER (WATTS)
HPS (BD-17)	6.43	18	3	2.14	6.00	122
HPS (ED-23)	6.06	20	3	2.02	6.67	122
Luminaire A	2.85	4	1	2.85	4.00	54
Luminaire B	2.53	5	1	2.53	5.00	49
Luminaire E	1.47	3	1	1.47	3.00	48
Luminaire F	2.58	4	1	2.58	4.00	70
Luminaire G	5.27	10	2	2.64	5.00	75
Luminaire H	4.58	16	2	2.29	8.00	75

*Luminaire A newer generation with higher efficacy and higher average LUX was implemented in the field study.

The inline placement at 100-foot spacing shows that while both uniformity ratios with the LED luminaires are, for the most part, close to the HPS baseline, the average and minimum illuminance values are much lower. Note that LED Luminaire's G and H have values fairly close to that of the baseline.

STAGGERED PLACEMENT

Staggered placement is where the street light poles are placed on both sides of the street in an alternating pattern as shown in Figure 7, below.

FIGURE 7. STAGGERED LUMINAIRES

Table 4 shows the simulation results for the 150 foot staggered spacing model using 600 data points. Note that the power values represent manufacturer ratings.

TABLE 4. STAGGER PLACEMENT – 150-FOOT SPACING

Luminaire	Average Illuminance (Lux)	Maximum Illuminance (Lux)	Minimum Illuminance (Lux)	Uniformity Ratio (Avg/Min)	Uniformity Ratio (Max/Min)	Power (Watts)
HPS (BD-17)	4.33	17	1	4.33	17.00	122
HPS (ED-23)	3.96	19	2	1.98	9.50	122
Luminaire A	1.86	4	1	1.86	4.00	54
Luminaire B	1.75	5	1	1.75	5.00	49
Luminaire E	1.05	3	0	N/A	N/A	48
Luminaire F	1.84	4	1	1.84	4.00	70
Luminaire G	3.51	10	1	3.51	10.00	75
Luminaire H	3.04	15	1	3.04	15.00	75

*Luminaire A newer generation with higher efficacy and higher average LUX was implemented in the field study.

The staggered placement at 150-foot spacing shows that this spacing creates a challenge for the HPS baseline as well as the measure. Note that the average and minimum illuminances of the LEDs falls short in comparison with the baseline.

Although the average illuminances are less, the uniformity ratios show an improvement. Due to the zero minimum illuminance value of LED Luminaire E, the uniformity ratios were not calculated.

LABORATORY EVALUATION RESULTS

The laboratory evaluations tested four luminaires. These luminaires were chosen from the group of luminaires run through the simulations and one additional luminare that was just released at the time.

PHOTOMETRIC AND POWER DATA

Table 5 shows a summary of measured values for the four luminaires. Note that the luminaires evaluated were selected based upon results obtained by the initial simulations. The exact luminaires tested do not directly compare with each other; rather they indicate the cross section of luminaire types available from manufacturers.

TABLE 5. INTEGRATING SPHERE TEST RESULTS FOR LUMINAIRES

LUMINAIRE	LUMINOUS FLUX (LUMENS)	CCT (KELVIN)	CRI	POWER (W)	EFFICACY (LUMENS/WATT)
Luminaire A	6,022	5,449	64	91.2	66.0
Luminaire B	3,818	4,014	81	69.2	55.2
Luminaire H	2,807	5,196	71	55.3	50.8
Luminaire I	5,461	6,014	70	78.1	69.9
HPS	6,671	1,955	16	124.5	53.6

Overall the efficacies of the LED luminaires are higher than the HPS with the exception of Luminaire H. This could be due, in part, to the lower overall wattage or power of the fixture. Since the efficacies for the fixtures are relatively close the energy savings do not seem very high. However, the actual field testing will reveal any benefits from improved distribution over HPS.

Figure 8 shows the radiant spectral flux in milliwatts in the visible wavelength range for each of the four luminaires.

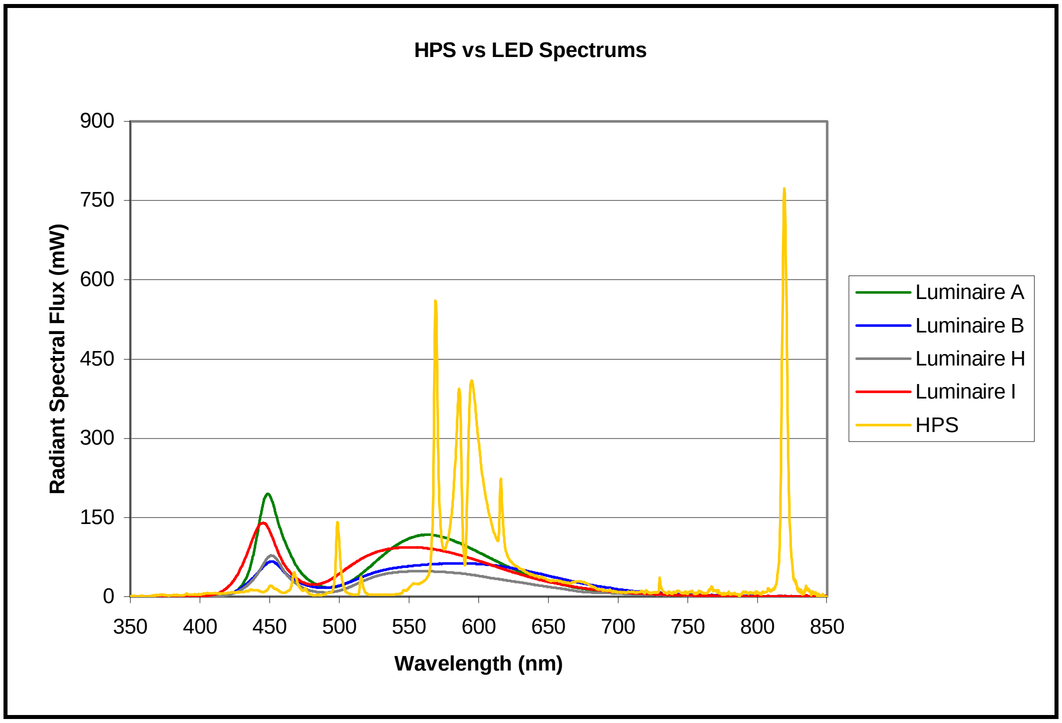


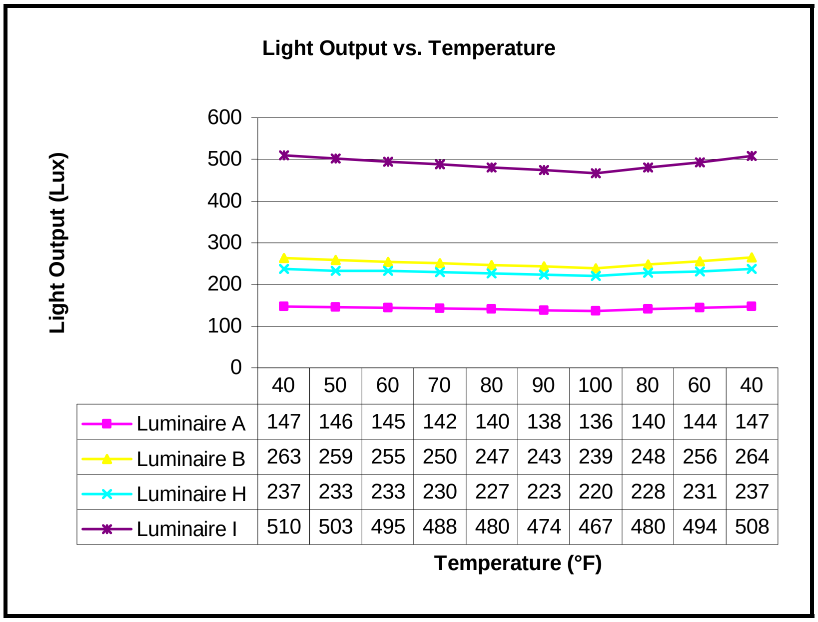
FIGURE 8. RADIANT SPECTRAL FLUX - LUMINAIRE SPECTRUMS

The peaks in Figure 8 indicate the dominant wavelength that plays a role in the overall CCT and CRI. Total light output can be taken as the total area under the graph. Note that the HPS spectrum is set to the secondary axis on the chart due to the higher intensity yet narrow peak.

The LED spectrums are typically of white LEDs that start with a blue LED base coated with a yellow phosphor to produce white light.

TEMPERATURE-DEPENDENCY DATA

The chart in Figure 9 shows the effects of temperature on light output. The chart indicates that light output has a linear decrease as temperature increases for all the luminaires. As temperature decreases the luminaires very closely matched the light output values at the increasing stabilization temperature points. This indicates no permanent degradation from a high temperature of 100°F.

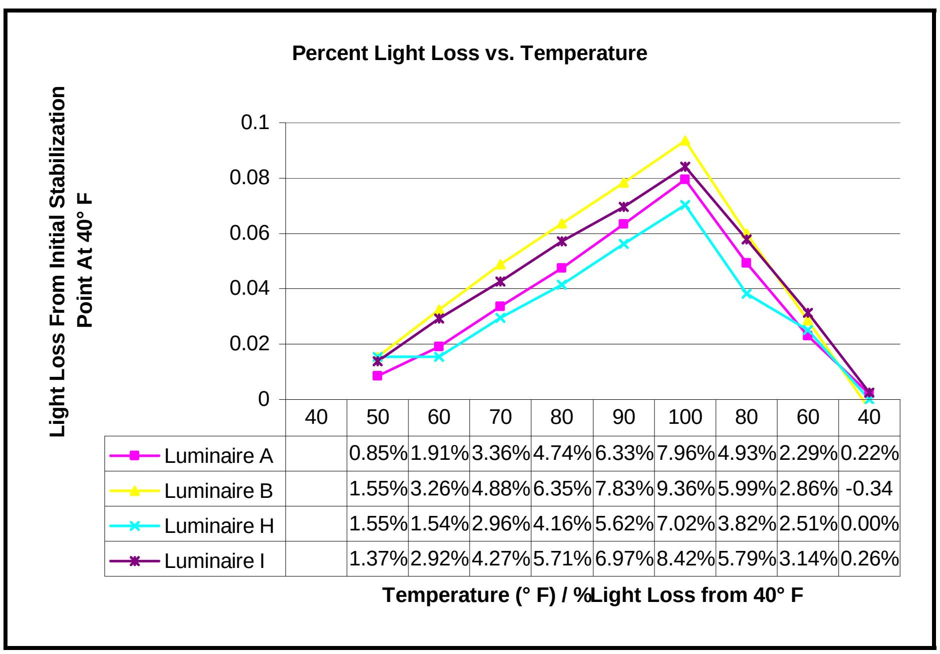


	40	50	60	70	80	90	100	80	60	40
Luminaire A	147	146	145	142	140	138	136	140	144	147
Luminaire B	263	259	255	250	247	243	239	248	256	264
Luminaire H	237	233	233	230	227	223	220	228	231	237
Luminaire I	510	503	495	488	480	474	467	480	494	508

FIGURE 9. LIGHT OUTPUT TEMPERATURE DEPENDENCY

Luminaire I, which is a larger wattage luminaire, shows a slightly larger decrease in light output with increased temperature. This is indicated by the slightly steeper slope. This is more easily indicated in Figure 10 that shows the relative percent light loss with respect to the initial output at 40°F.

Figure 10 shows the amount of light loss from the initial stabilization point of 40°F. The data indicates that a 60° delta increase in temperature results in a light output decrease of approximately 8% to 9%. This can be a significant amount when taking into consideration the defined end-of-life of an LED luminaire (L_{70}) that is 30% of its initial output.



	40	50	60	70	80	90	100	80	60	40
Luminaire A		0.85%	1.91%	3.36%	4.74%	6.33%	7.96%	4.93%	2.29%	0.22%
Luminaire B		1.55%	3.26%	4.88%	6.35%	7.83%	9.36%	5.99%	2.86%	-0.34
Luminaire H		1.55%	1.54%	2.96%	4.16%	5.62%	7.02%	3.82%	2.51%	0.00%
Luminaire I		1.37%	2.92%	4.27%	5.71%	6.97%	8.42%	5.79%	3.14%	0.26%

FIGURE 10. PERCENT LIGHT LOSS DUE TO TEMPERATURE

FIELD ASSESSMENT RESULTS

The field assessments include continuous monitoring of temperature and power from the luminaires at the field locations as well as spot measurements for the baseline and measure. Two LED luminaire manufacturers were selected for the field assessments based upon their performance from the simulations and laboratory data. The luminaires selected are A and H.

A total of four test locations were selected in four different climate zones to give a representation of the broad range of climate zones within SCE service territory

Two sets of monitoring equipment were placed at each site to monitor the baseline HPS and each of the two LED luminaire types.

The initial phase of the field assessments was to install new HPS luminaire with new lamps and ballasts and conduct a minimum 100 hours of burn-in. This was to ensure that the comparisons were made to new luminaires.

TEST SITES

Four sites were selected for spot measurements and continuous monitoring. These sites were selected based upon the availability of streets with suitable fixtures as well as California Climate Zones (CZ).[4]

TABLE 6. TEST SITES AND CORRESPONDING CLIMATE ZONES

CITY	CZ	DESCRIPTION
Ventura	6	Coastal Area
Rosemead	9	Metropolitan
Tulare	13	Central Valley
Palm Springs	15	Desert

VENTURA

The city of Ventura test site was conducted on two residential streets in a single-family housing neighborhood.

The two streets used for the spot measurements are Candytuft Street (Luminaire F) and the northern half of Bluebonnet Avenue (Luminaire A). Each street contained four fixtures in a staggered placement. The baseline luminaires were 70W HPS at 240V.

ROSEMEAD

The city of Rosemead test site was conducted on two residential streets in a single-family housing neighborhood

The two streets used for the spot measurements are La Presa Avenue (Luminaire H) and Paljay Avenue (Luminaire A). Each street contained 9 fixtures in an inline placement. The baseline luminaires were 100W HPS at 120V.

Both streets were virtually identical with respect to pole spacing.

TULARE

The city of Tulare test site was conducted on two residential streets, one along single-family housing and the other along duplex-style housing.

The two streets used for the spot measurements are Yellowstone Street (Luminaire H) and Delaware Avenue (Luminaire A). Each street contained 9 fixtures in an inline placement. The baseline luminaires were 70W HPS at 120V.

Yellowstone Street consisted of single-family housing while Delaware Avenue consisted of duplex-style housing. This added a slightly different perspective regarding traffic.

PALM SPRINGS

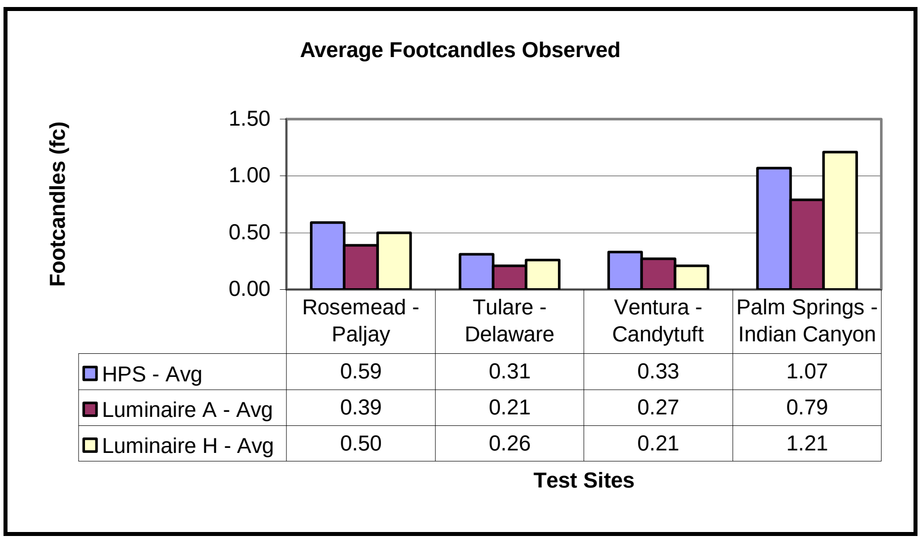
The city of Palm Springs test site was conducted on a four-lane one-way street along commercial property.

The street used for the spot measurements is North Indian Canyon Boulevard (Luminaires A and H). The section of the street tested between East Alejo Road and East Amado Road contained 11 fixtures in an inline placement. The baseline luminaires were 200W HPS at 120V.

FIELD SPOT TEST DATA

The field spot tests involved measurements and simulations using the exact geometries of the street. In real-world applications street lighting poles are not set up perfectly spaced due to placements of driveways, fire hydrants, etc.

Figure 11 shows the field measurement data for average illuminance at each of the four field test sites. Overall, in comparison with HPS the LED luminaires have lower average illuminance values than the HPS luminaires. Luminaire A for the Rosemead site comes close to meeting the HPS average illuminance.



	Rosemead - Paljay	Tulare - Delaware	Ventura - Candytuft	Palm Springs - Indian Canyon
HPS - Avg	0.59	0.31	0.33	1.07
Luminaire A - Avg	0.39	0.21	0.27	0.79
Luminaire H - Avg	0.50	0.26	0.21	1.21

FIGURE 11. AVERAGE FOOTCANDLES OBSERVED

Figure 12 shows the field measurement data for maximum illuminance at the four field test sites. Overall in comparison with HPS the LED luminaires have much lower maximum illuminance values than the HPS luminaires. Luminiare H is very close to meeting the maximum illuminance of the HPS for the Rosemead site and the same luminaire exceeds the maximum for the Palm Springs site. Also at the Palm Springs site, Luminaire A comes close to the HPS maximum illuminance.

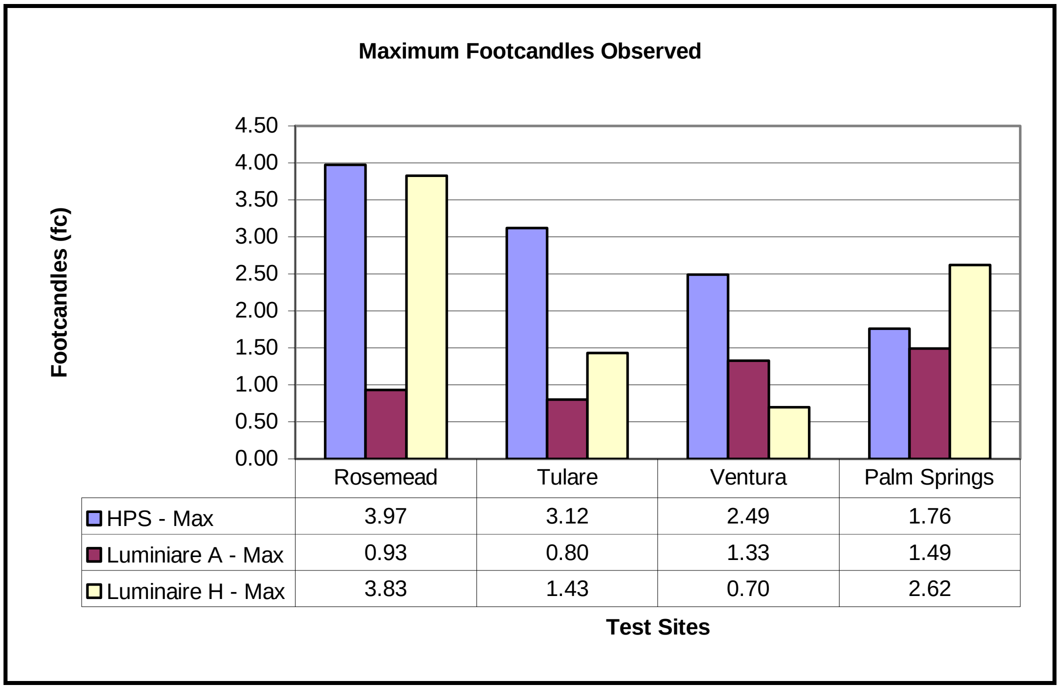
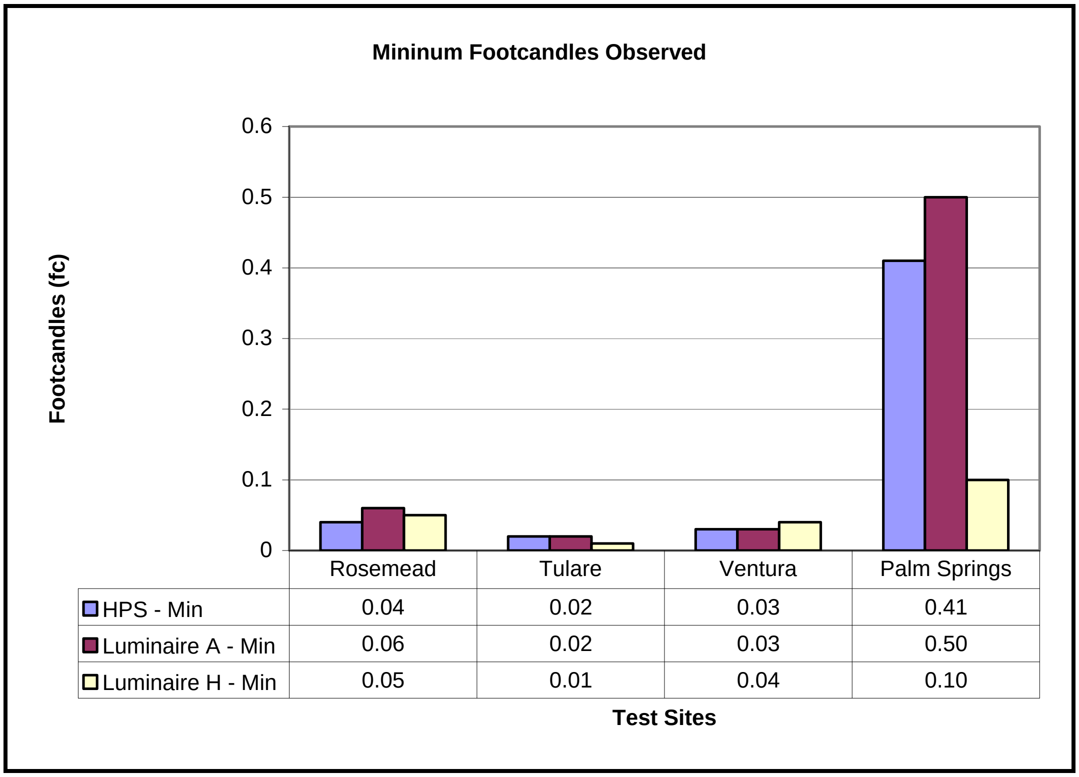


FIGURE 12. MAXIMUM FOOTCANDLES OBSERVED

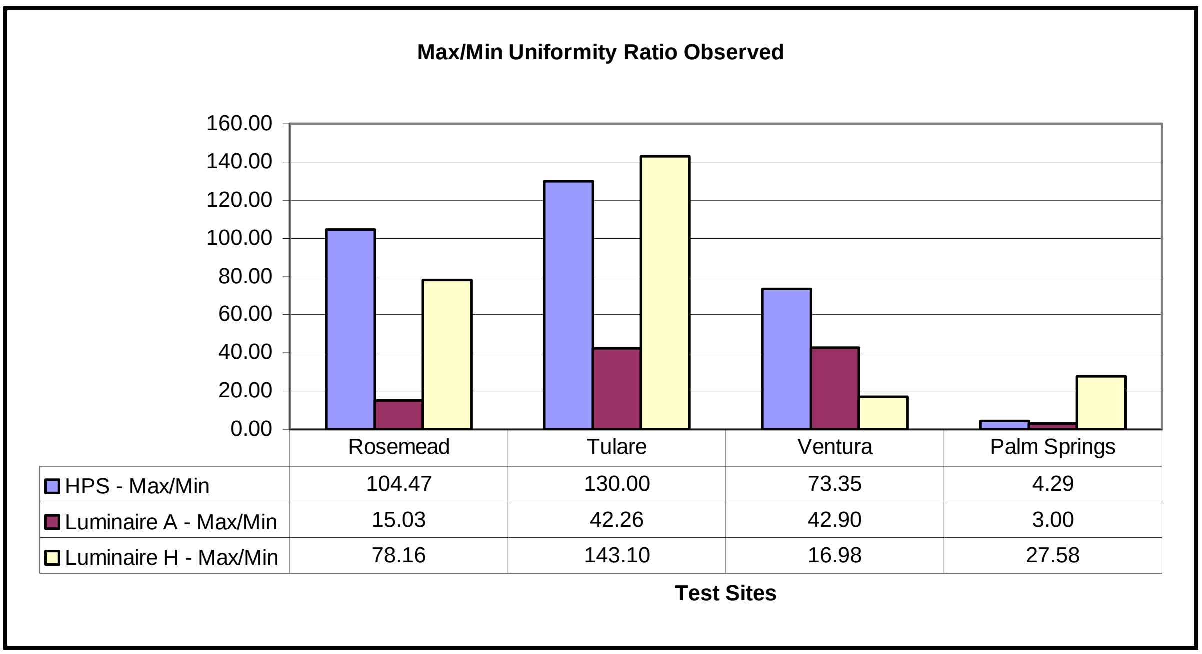
Figure 13 shows the field measurement data for minimum illuminance at the four field test sites. Overall, in comparison with HPS the LED luminaires meet or exceed the minimum illuminance values at each of the test sites with the exception of Luminaire H in Tulare. Note that the much higher overall minimum illuminance values for the Palm Springs site indicate the type of street that has a larger and higher traffic road than the residential type streets at the other sites. Luminaire H has much lower minimum illuminance values than HPS at the Palm Springs field test site, most likely due to the lower overall wattage than the Luminaire A unit.



	Rosemead	Tulare	Ventura	Palm Springs
HPS - Min	0.04	0.02	0.03	0.41
Luminaire A - Min	0.06	0.02	0.03	0.50
Luminaire H - Min	0.05	0.01	0.04	0.10

FIGURE 13. MINIMUM FOOTCANDLES OBSERVED

Figure 14 shows the Max/Min uniformity ratio observed in the field measurements. The lower number represents a much more uniform distribution in that there is less of a difference between the dark and bright spots. Luminaire A has consistently improved uniformity than the HPS for all sites, however Luminaire H tends to vary.



	Rosemead	Tulare	Ventura	Palm Springs
HPS - Max/Min	104.47	130.00	73.35	4.29
Luminaire A - Max/Min	15.03	42.26	42.90	3.00
Luminaire H - Max/Min	78.16	143.10	16.98	27.58

FIGURE 14. MAX/MIN UNIFORMITY RATIO OBSERVED

Figure 15 shows the Avg/Min uniformity ratio observed in the field measurements. The lower number represents a much more uniform distribution in that there is less of a difference between the average illuminance and minimum illuminance values. Luminaire A has consistently improved uniformity than the HPS for all sites. However Luminaire H tends to vary where it has much worse uniformity values than HPS at the Tulare and Palm Springs sites, but improved uniformity values at the Rosemead and Ventura sites.

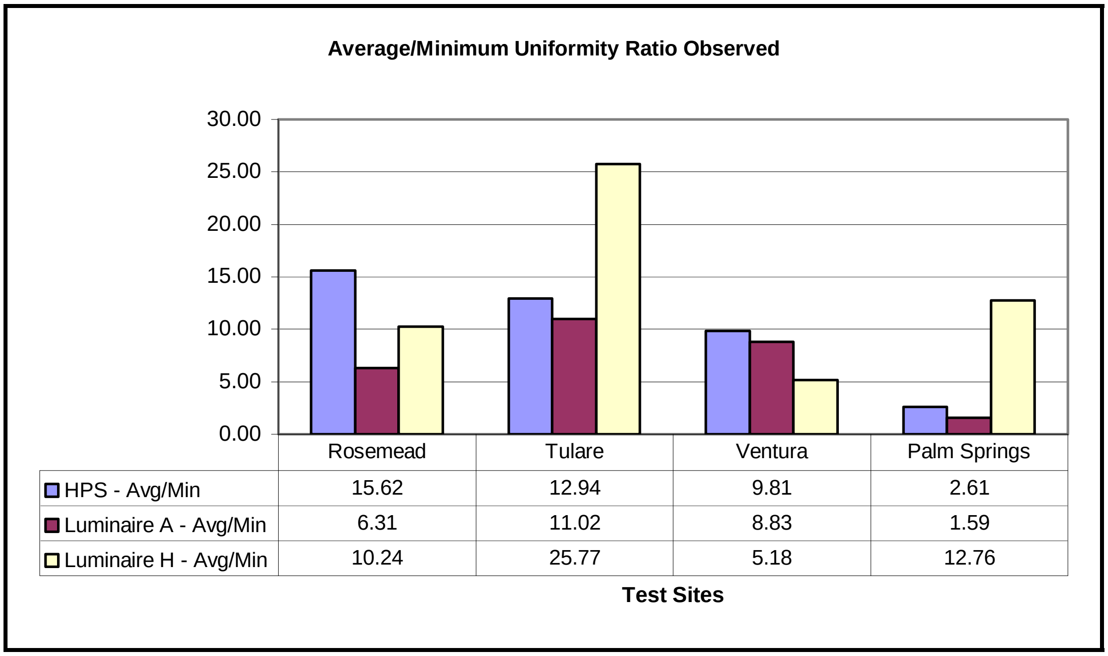


FIGURE 15. AVG/MIN UNIFORMITY RATIO OBSERVED

Overall, Luminaire A performed much more consistently than Luminaire H. None of the fixtures met the average illuminance values of the HPS with Luminaire H coming close for the Rosemead and Palm Springs sites. With respect to minimums the fixtures meet the minimum illuminances of the HPS luminaires. Both uniformity values of Luminaire A were consistently better than HPS throughout all test sites. This indicates a much more even distribution of the light being emitted from the luminaire.

FIELD LOGGING DATA

The data obtained from the field logging equipment monitors thermal characteristics at each test site for ambient and internal lighting to the fixture. Voltage, current and power was also measured.

All test sites were assumed to be 120V sources however during the installation process it was found that the Ventura site was in fact a 240v source. As a result, only power was measured due to the additional configuration of the sensors at the Ventura test site.

POWER

Figure 16 shows the power measured from each of the luminaires tested. Note that the power measurements were taken on the eighth night after installation due to a burn-in period for the HPS. The LED luminaires do not require a burn-in period and as such the measurements were taken from the first night after installation. Due to the pole design at Palm Springs, the monitoring equipment was not installed. A suitable pole in close proximity was identified and installed. The data for Palm Springs in Figure 16 were taken from laboratory measurements and not from actual field test data.

Note the LED luminaires show a significant reduction in power from their HPS counterparts.

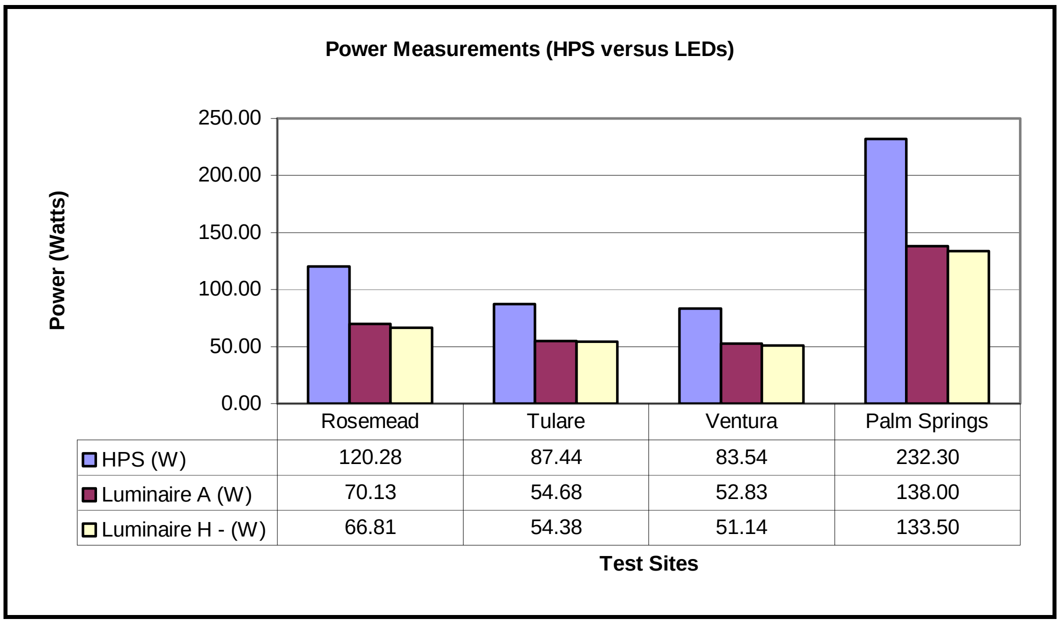


FIGURE 16. POWER MEASUREMENTS (HPS VERSUS LEDS)

THERMAL MONITORING

The field installations started in early October 2009 and as a result the climate had started to cool for the winter. Due to the October installation the yearly high temperatures that typically occur around August/September are not yet recorded.

However, operational data of the internal temperatures of the fixtures were monitored. This monitoring is imperative for the LED luminaires as the power supplies - or "drivers," contain electronics that may be sensitive to extreme temperatures that may be evident inside the fixture. Table 7 shows both the ambient and internal high/low temperatures.

TABLE 7. TEMPERATURE EXTREMES MONITORED

LOCATION/ FIXTURE	AMBIENT (°F) LOW | HIGH	INTERNAL 1 (°F) LOW | HIGH	INTERNAL 2 (°F) LOW | HIGH
Rosemead - Luminaire A	34 | 85	59 | 84	37 | 84
Rosemead - Luminaire H	33 | 84	49 | 84	52 | 88
Tulare - Luminaire A	36 | 78	63 | 76	40 | 76
Tulare - Luminaire H	38 | 77	53 | 79	56 | 77
Ventura - Luminaire A	33 | 70	58 | 72	41 | 72
Ventura – Luminaire H	34 | 69	42 | 71	40 | 73
Palm Springs – Luminaire A*	N/A	N/A	N/A
Palm Springs – Luminaire H*	N/A	N/A	N/A

*Due to the arm lengths of the street light poles, the monitoring equipment was not able to be installed for Palm Springs. A suitable pole in the vicinity has been identified and the monitoring equipment will be installed on that pole.

Note that the luminaires were only exposed to a high of 85°F during operation and was not exposed to higher temperatures which are typical for the summer months. On the other hand, the luminaires were exposed to very low ambient temperatures. The temperature sensitivity of the technology lends itself to better performance and life at lower temperatures than at high temperatures.

Interestingly, at the higher ambient temperatures, the internal temperatures for the LED luminaires were almost identical in most cases. This shows that the internal driver is not exposed to excessively high temperatures within the luminaire and helps to support the potential for longevity. Again, the data does not indicate if this trend continues at higher ambient temperatures upwards of 100°F.

FIELD INSTALLATION FEEDBACK

The installations for the luminaires were conducted by SCE street light repairmen. Although the LED luminaires are intended and designed as direct replacements to HPS cobraheads, there are some differences that were realized at the time of installation.

LUMINARE A

The mounting system on Luminaire A used the typical notched adjustment plates and 2-bolt bracket that is commonly used on HPS cobrahead mounting systems. This made for a straight forward task when physically mounting the luminaire. Wiring the luminaire however, was a challenge due to the terminal block placement as shown in Figure 17.

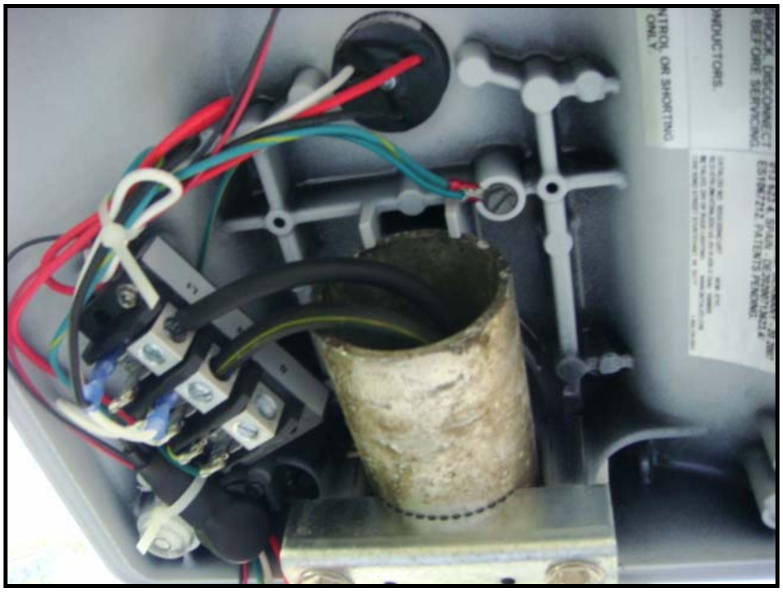


FIGURE 17. LUMINAIRE A TERMINAL BLOCK LOCATION

The terminal block is located very close to the mast arm which makes it difficult to bend and insert the wires into the terminal block.

LUMINAIRE H

The mounting system on Luminaire H presented additional challenges as it uses a 4-bolt clamp-type design as shown in Figure 18. Note that loosening of the mounting bracket to slip it on the mast arm is limited by the luminaire housing. In some cases all four bolts needed to be completely removed prior to installation. Also, the terminal block design uses smaller screws that were inset in the terminal block housing requiring a thinner slotted screw driver.

There are two additional issues of concern noted from the field installations:

The luminaire uses a length of steel aircraft cable to secure the access hatch when opened. This design does allow for flexibility and security when the hatch is open, but the issue occurs when closing the hatch as the cable is pushed into the fixture with the potential of making contact with the terminal block.

The mounting of the photocell tends to make a full 360° rotation before locking when inserting the photocell. The concern is the binding of the wires inside the luminaire.

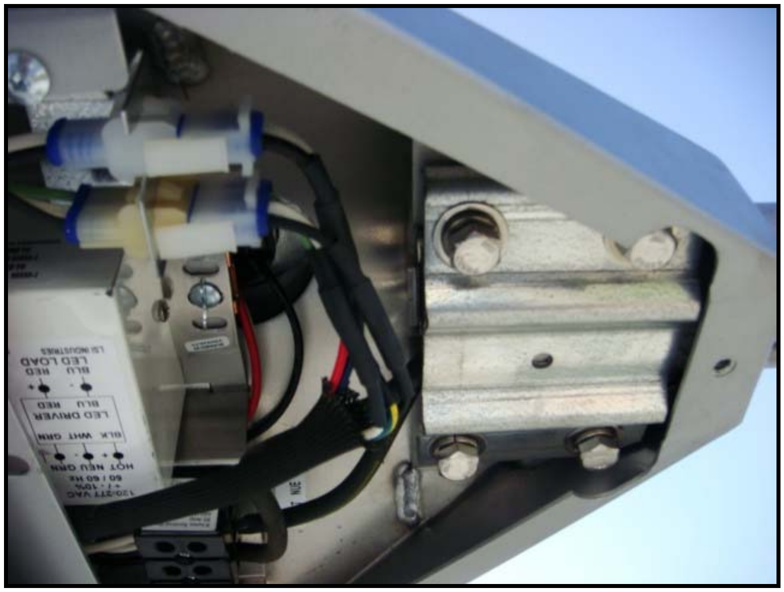


FIGURE 18. LUMINAIRE H MOUNTING SYSTEM

COST ANALYSIS

The cost of HPS luminaires is relatively inexpensive as the technology is well past maturity in the market. LED luminaires for street lighting, however, have only been in the market for a few years. The typical cost for a LED street lighting luminaire was upwards of $3,000 just a few years ago and is steadily dropping each year.

LUMINAIRE COSTS

Table 8 shows the costs of the luminaires used in the field tests along with specific SCE costs and typical retail costs of HPS fixtures. On average LED luminaires are up to five times higher in cost. These costs are based on small quantity orders, but when dealing in larger quantities the costs may be lower. Note that the cost for HPS includes the luminaire and lamp. Neither the HPS nor LED luminaire costs include the photocell. Cost values for HPS are a representation of average retail costs and LEDs represent the costs paid for fixtures ordered for the assessment. The market low/high costs are estimated based upon distributor quotes for large quantities. The associated wattages are based upon the highest wattage of the two luminaires that were field tested.

TABLE 8. LUMINAIRE WITH LAMP COSTS

NOMINAL WATTAGE	HPS – RETAIL ($)	LUMINAIRE A ($)	LUMINAIRE H ($)	MARKET PRICE LOW	MARKET PRICE HIGH
70W	*150.00	425.00 (56W)	500.00 (42W)	388.00† (56W)	525.00† (56W)
100W	*150.00	500.00 (72W)	500.00 (63W)	483.00† (72W)	735.00† (72W)
200W	*300.00	920.00 (142W)	700.00 (119W)	672.00† (142W)	1090.00† (142W)

*Approximate Industry Average based on distributor data.

†Estimated volume cost based upon distributor quotes.

INSTALLATION COSTS

Installation costs for HPS and LED luminaires are the same. The cost values in Table 9 indicate the retail cost for installation. This value however, does not include any overhead incurred by cities and municipalities.

TABLE 9. INSTALLATION COSTS

TYPE	COST ($)
Retail	150.00*

*Approximate Industry Average for low quantities.

LUMINAIRE LIFE

Due to the short duration of the tests and the high-rated life of LED fixtures, manufacturer's ratings are used to calculate the lifecycle cost. Rated life is defined as the point when the light output from the fixture reaches 70% of its initial light output (L_{70}). The Illuminating Engineering Society of North America (IESNA) provides a standard on the life of LED technology; however that standard is limited to the LED chips only and provides a methodology for the measurement of life within a limited time frame. It does not go beyond to predict the life of the LED for the duration of the manufacturer-rated life. Also, the stated warranties for the LED luminaires are for 5 years. This translates to 21,900 hours at 12 hours a day.

Table 10 shows the rated life of the luminaires tested. The industry average is typically 50,000 hours and varies greatly between products and applications. Luminaire A rates their fixture at 107,000 hours if operated at an ambient temperature of 59°F while Luminaire H offers a range between 60,000 and 100,000 hours depending on temperature. This is a significant variation in lifetimes that emphasizes the effect that temperature has on LED technology.

TABLE 10. LUMINAIRE RATED LIFE

LUMINAIRE	RATED LIFE (HOURS)
HPS	24,000
Luminaire A	107,000
Luminaire H	60,000-100,000
LED Industry Average	50,000

In most cases the installations of the LED fixtures do not vary from that of a standard cobrahead luminaire. Common field practice replaces the entire HPS cobrahead luminaire rather than just replacing a lamp. This is due to greater simplicity than unscrewing a lamp and cleaning the reflectors and lenses. For the purpose of comparison the installation cost is assumed the same for HPS and LED.

LIFECYCLE COST CALCULATIONS

METHODOLOGY

Due to the extended rated life of the LEDs in comparison with HPS, the full costs need to be normalized in order to obtain a direct comparison. The Lifecycle Cost (LCC) calculation is calculated using Equation 3.

EQUATION 3. LIFECYCLE COST

$$\text{LCC} = \text{Capital Cost} + \begin{pmatrix} \text{Present Worth} \\ \text{of Maintenance} \end{pmatrix} + \begin{pmatrix} \text{Present Worth} \\ \text{of Energy} \end{pmatrix} - \begin{pmatrix} \text{Present Worth} \\ \text{of Salvage Value} \end{pmatrix}$$

Where:

Capital Cost = The cost of the equipment and installation

The present worth values for Maintenance, Energy and Salvage Value are calculated using Equation 4, Equation 5, and Equation 6.

EQUATION 4. PRESENT WORTH OF MAINTENANCE

$$\begin{pmatrix} \text{Present Worth} \\ \text{of Maintenance} \end{pmatrix} = \frac{(\text{MpY}) \times \left(1 - (1 + \text{NDR})^{-\text{Y}}\right)}{\text{NDR}}$$

Where:

MpY = Yearly maintenance costs

NDR = Net Discount Rate: Expected inflation subtracted from a nominal investment rate, (for the calculations a default value of 5% is used).

Y = Number of years of equipment operation

EQUATION 5. PRESENT WORTH OF ENERGY

$$\begin{pmatrix} \text{Present Worth} \\ \text{of Energy} \end{pmatrix} = \frac{(\text{EpY}) \times \left(1 - (1 + \text{NDR})^{-\text{Y}}\right)}{\text{NDR}}$$

Where:

EpY = Yearly energy costs

NDR = Net Discount Rate: Expected inflation subtracted from a nominal investment rate, (for the calculations a default value of 5% is used).

Y = Number of years of equipment operation

EQUATION 6. PRESENT WORTH OF SALVAGE VALUE

$$\begin{pmatrix} \text{Present Worth} \\ \text{of Salvage Value} \end{pmatrix} = (\text{SV}) \times (1 + \text{NDR})^{-\text{Y}}$$

Where:

SV = Salvage Value Final Year: Total worth of equipment at its end of life (for the calculations a value of $5 is used for all luminaires).

NDR = Net Discount Rate: Expected inflation subtracted from a nominal investment rate, (for the calculations a default value of 5% is used).

Y = Number of years of equipment operation

CALCULATION RESULTS

The calculations aim to compare the LED luminaires with the HPS on the basis of LCC. Additional considerations with regard to the customer-owned LS-2 tariff are discussed in the next section.[1] The LCCs are calculated at the industry standard life rating of 50,000 hours. Although there are manufacturer claims of up to 100,000 hours, there is currently no industry-wide life standard. An energy rate of $0.075 per kWh was used for energy cost calculations.

Table 11 shows the calculated LCC comparisons at 21,900 hours of operation. This is equivalent to 5 years assuming the typical average of all night operation at 12 hours per day. This value reflects the manufacturer warranties of the product.

TABLE 11. LIFECYCLE COSTS AT 21,900 HOURS

LUMINAIRE	70W HPS REPLACEMENT LCC ($)	100W HPS REPLACEMENT LCC ($)	200W HPS REPLACEMENT LCC ($)
HPS	421	467	773
LED Market Low	614	731	1,020
LED Market High	751	983	1,438

Although the time period of 5 years is very short for a lifecycle calculation, it is based upon the warranty period of the product to ensure that the LED luminaire is still in operation. Note that this time period is close to the effective useful life (EUL) of HPS and for all the cases, both the Market High and Low show a significantly higher LCC.

Table 12 shows the calculated LCC comparisons at 50,000 hours of operation. This is equivalent to 11.4 years assuming the typical average of all night operation at 12 hours per day. This value reflects the common industry standard with regard to LED luminaire life. The calculation includes one replacement of the HPS luminaire.

TABLE 12. LIFECYCLE COSTS AT 50,000 HOURS

LUMINAIRE	70W HPS REPLACEMENT LCC ($)	100W HPS REPLACEMENT LCC ($)	200W HPS REPLACEMENT LCC ($)
HPS	768	858	1429
LED Market Low	692	832	1217
LED Market High	829	1084	1635

This time period reflects one replacement of the HPS luminaire. For all the cases the LED Market Low LCCs are lower, with the 100W HPS being only marginally lower. The HPS costs are in between the Highs and Lows indicating a fairly volatile market.

Table 13 shows the calculated LCC comparisons at 100,000 hours of operation. This is equivalent to 22.8 years assuming the typical average of all night operation at 12 hours per day. This value reflects the manufacturer-rated life times under ideal conditions that range around 100,000 hours depending on luminaire size.

TABLE 13. LIFECYCLE COSTS AT 100,000 HOURS

LUMINAIRE	70W HPS REPLACEMENT LCC ($)	100W HPS REPLACEMENT LCC ($)	200W HPS REPLACEMENT LCC ($)
HPS	1393	1004	1728
LED Market Low	783	949	1447
LED Market High	920	1201	1865

This calculation assumes 3 HPS luminaire replacements. Currently, there is no standard to help support the life rating of the LED luminaire for this time period, however, if 100,000 hours can be realized, there are cost benefits in some cases.

Throughout the calculations, it became evident that the unknown factor was the true life of the LED product. Extended warranties may help to ensure the life of the product however, even at a 100,000 hour LCC the savings are not realized for all cases.

The cost of luminaires is the largest impact on the LCC. The reduction of fixture costs by using fewer LED chips, with higher efficacy, will aid in increasing LCC savings. Figure 19 indicates the break even points, in price, that an LED luminaire must meet in order to match the LCC or HPS at a 50,000 hour time period. Note that the red squares indicate the LED Market High, the green circles indicate LED Market Low and the yellow triangles indicate the LED Break-Even Point (BEP). This shows that LED technology is still emerging along with a volatile LED luminaire market.

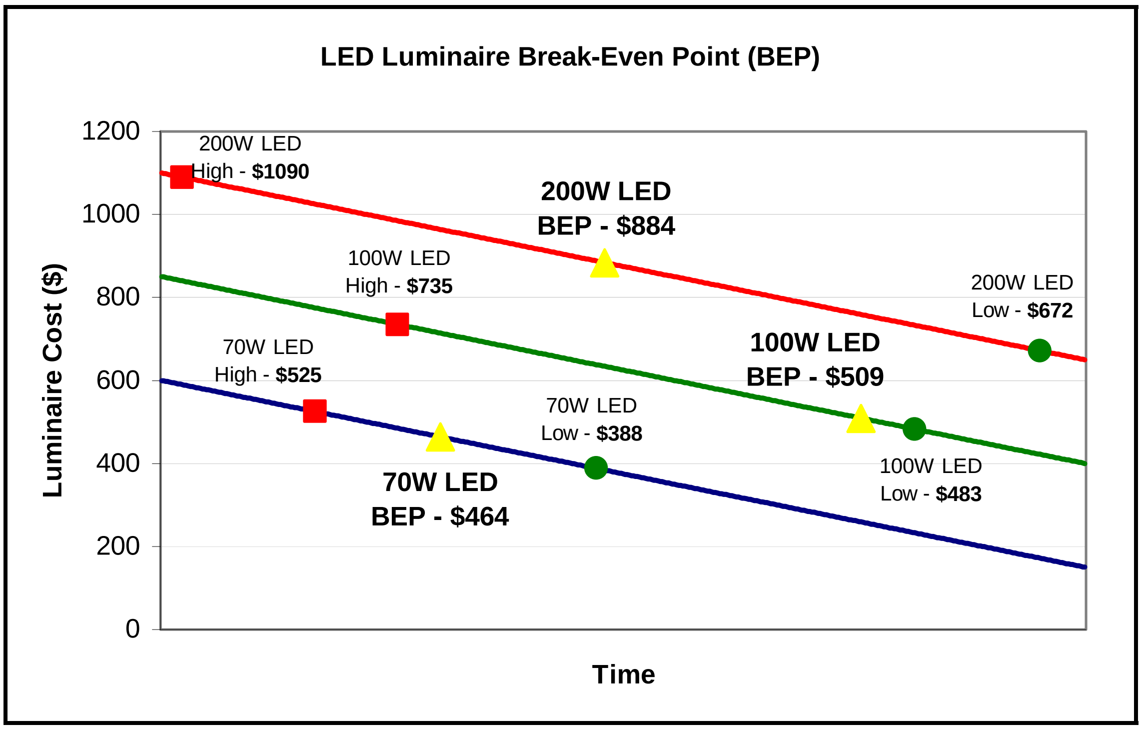


FIGURE 19. HPS VERSUS LED LIFECYCLE COST BREAK-EVEN POINTS

TARIFF CONSIDERATIONS

There are three rate structures for street lighting luminaires within the SCE service territory. As of August 2009, LED technology was added to the tariff.

- LS-3 Tariff – is a metered rate for customer-owned and operated street lights. Energy savings are derived from baseline energy usage and measure energy usage observed via the meter, and thus billed accordingly.
- LS-1 Tariff – is a SCE-owned and operated rate that includes all maintenance costs as well as energy, and are considered capital and, therefore, are not eligible for efficiency incentives funded by a public goods charge.
- LS-2 Tariff – is a customer-owned and operated rate that does NOT include all the maintenance and operation costs, but does include energy costs.

Figure 20 is taken from a presentation on street light rates by SCE's Tariff group which shows how much of the rate is dependant on energy for both the LS-1 and LS-2 tariffs.[5] Note that the Generation and Others portions of Figure 20 are energy cost contributors.

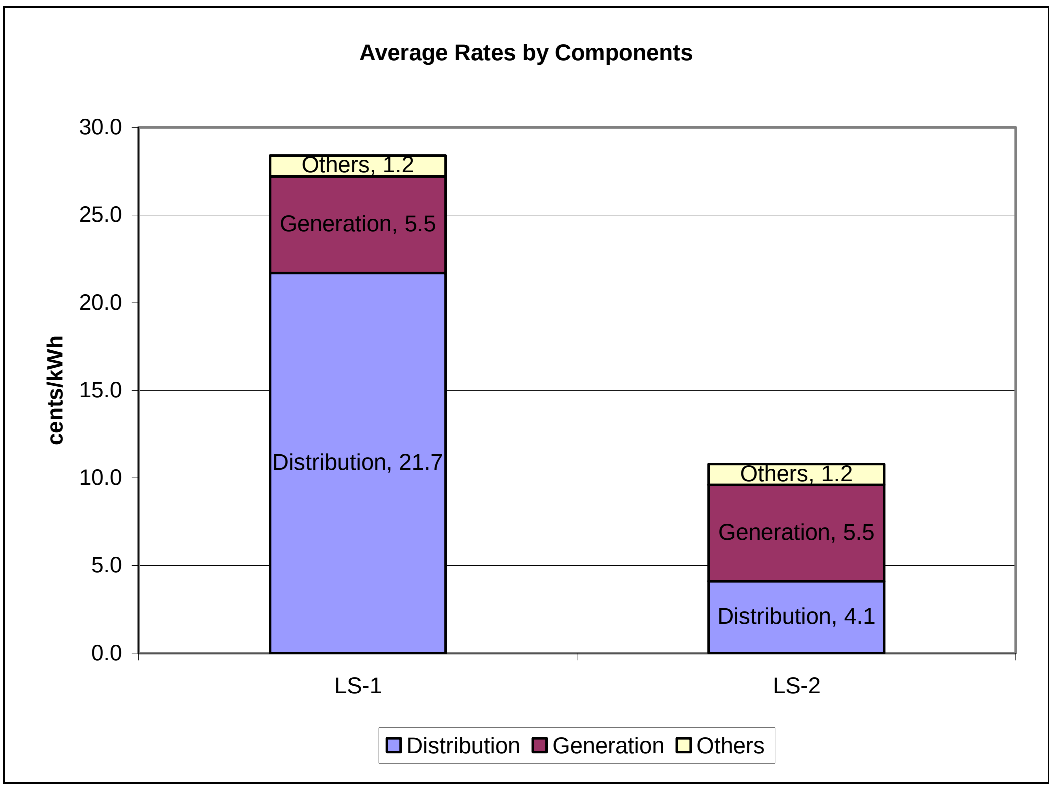


FIGURE 20. AVERAGE RATES BY COMPONENTS

Figure 20 above indicates the impact that energy costs have on tariffs. Note, for the LS-2 tariff the energy costs (Generation & Others) make up a considerable amount of the tariff - greater than 50%. This means that energy savings makes a larger impact on the resulting costs than that of the LS-1 tariff where energy costs are only approximately 25% of the total rate.

The Cost Analysis section highlights the differential of costs between SCE and Retail for HPS cobraheads with LED luminaires, for the moment, remaining equal in cost for both SCE and Retail. When applying this to the LS-1 tariff the energy savings and maintenance reductions may not be sufficient at this time to offset the differential in luminaire costs. The LS-2 tariff on the other hand has a much greater impact from an energy savings standpoint; however the customer must also consider their installation and tariff costs for the luminaires. This is where the LCC comparisons, discussed in the previous section, will help to determine the cost reduction potential.

CONCLUSIONS

This project aimed to determine the feasibility of replacing HPS cobrahead-style luminaires with LED luminaires in order to achieve energy savings. There are many factors which play a role in considering a replacement. The data from this testing indicates that the LED fixtures show significant energy savings with LED technology when compared to HPS. However, the average illuminances were reduced while Minimum illuminances were maintained and uniformity was improved.

The depreciation of HPS technology is well established with a rated life of 24,000 hours. LED depreciation however, varies greatly. The short duration of the testing did not lend itself to reveal any significant depreciation due to normal operation and there are many other factors in determining the life of the product.

LED technology is temperature-dependant and as indicated in the lab tests there can be a fairly significant depreciation in performance with increased temperatures. Although this effect is typically mitigated by night operation, there are many areas within SCE service territory that can reach overnight temperatures of over 100°F. The continuing field monitoring has so far logged the temperature highs and lows over the coolest periods of the year. Although the luminaires have not seen ambient temperatures over 85°F during operation, the internal luminaire temperatures seem fairly stable and in most cases not much higher than ambient.

The field testing shows a wide variation in operating temperatures within a few months and may vary LED performance as indicated in the laboratory testing. Also, there are luminaire mounting designs to consider as one of the luminaires tested created some concerns and challenges during installation.

The LED first costs compared to HPS are still very high. Ordering in small quantities, the costs are typically up to five times higher. The luminaires are rated with lifetimes at 100,000 hours in specific cases; however this may not be the norm. If the application is in a cooler climate all indications show that there are significant savings with LED. There is added benefit as the extended lifetime also reduces needed maintenance. Note, however, that lifetime testing standards for LED technologies are still not developed and assuming an industry standard of 50,000 hour LED lifetimes the maintenance savings are reduced. When considering the LCC of the luminaires at different periods of operation, the SCE cost of equipment and installation is much less than that of retail and therefore requires a longer period of time to achieve cost savings. This is assuming that the rated lifetimes for the LED luminaire manufacturers hold true.

At this time the LED luminaires are not necessarily a cost-effective replacement for HPS. The LCC calculations show that the current cost of LED luminaires is one of the major factors in determining total cost savings over HPS. The Market Low for larger quantities at this time results in lower LCCs than that of HPS when compared at a 50,000 hour life. However, the larger initial costs may still be a barrier.

RECOMMENDATIONS

This project intended to gain initial insight into the current state of LED technology and provide a foundation for further testing. The monitoring equipment is designed for long-term testing and provides valuable data if allowed to be left in place throughout an entire year. This allows time to capture thermal data from the warmer times in the year.

An expanded laboratory test with more aggressive environments to better stress test the luminaires will help to ensure not only the quality of the product but the resiliency of the technology.

The field tests show that although the LED luminaires reduced energy savings they did not meet the average illuminances of the HPS. Additional testing using luminaires with greater light output, as recommended by the manufacturer, may show the ability to meet the averages, but may come as the result of increased energy consumption from the luminaire effectively reducing energy savings. Additional scaled field placements would be a benefit as well.

Also, periodic field spot measurements at the same sites will help to indicate how the luminaire light depreciation is occurring. In addition to the field installations, 24/7 monitoring of LED luminaires in a lab environment will help to create a better understanding of light depreciation.

There are many standards for the technology and roadway application that are still in flux. At this point it is difficult to make decisions with limited tools and metrics. Further involvement and interaction with not only the industry, but Standards organizations will help to push forward standards initiatives. The mutual benefit is a better understanding of the technology and its advancements.

LED technology is continuing to advance rapidly and as a result there are numerous improvements and products released to the market since the beginning of this project. Further testing of these new luminaires as they are released will help to better track the performance of these products.

Rapid advancements and cost reductions are characteristics of any emerging technology. This is an important point in that this technology is continuing to emerge and should not be treated as a commodity item. Educating SCE’s customer base will ensure that the LED technology continues to mature and gain market acceptance.

Also, there are many industry initiatives throughout the country that are looking toward reducing energy usage by street and area lighting. Among the parties heavily involved are the Department of Energy (DOE), IESNA, LED Manufacturers and other utilities. Although standards are still not available, advanced controls of street lights are an avenue to consider for testing that may help toward the development of standards. SCE should increase it’s participation in the continuous development of roadway specific standards (i.e., IESNA RP-8).

Each utility has a different situation when it comes to rates and tariffs and unlike the other California Investor Owned Utilities (IOUs), SCE owns and operates almost 80% of the street lights within its territory, the other 20% are customer-owned and operated. This difference, and its implications, is not always apparent to the customer base, but it is a valuable opportunity to educate and assist customers with their energy needs.

Based upon the BEPs determined in the 50,000 hour LCC analysis, on the low end LED luminaires can result in savings, however, on the high end they do not. The actual BEPs are bolded in Table 14 below.

TABLE 14. LED BREAK-EVEN POINTS

LUMINAIRE	MARKET HIGH ($)	MARKET LOW ($)	BREAK-EVEN ($)
70W HPS	525	388	**464**
100W HPS	735	483	**509**
200W HPS	1090	672	**884**

Performance improvements and volatile, yet dropping overall costs are key indicators of an emerging technology. Depending on the actual lifecycle costs for specific applications, LED Street Light luminaires are advancing toward becoming an energy efficient option.

Appendix A – Technology Test Centers

Location

All laboratory tests, referenced in this report, were conducted at SCE's Technology Test Centers (TTC) in Irwindale, California.

Technology Test Centers

The mission of the TTC is to spread awareness of viable integrated demand-side management solutions to a wide range of SCE customers and energy efficiency (EE) programs. Through impartial laboratory testing and analysis of technologies, the portfolio of EE measure offerings can be expanded with quantified energy savings and alleviation of concerns about performance uncertainties. Testing in a laboratory setting allows for the performance of detailed and replicable tests that are realistic, impartial, and not influenced by unwanted variables while in a controlled environment.

The TTC includes the Refrigeration and Thermal Test Centers, and the Southern California Lighting Technology Center (SCLTC).

Refrigeration and Thermal Test Center

Controlled environment testing is conducted at the TTC's Refrigeration and Thermal Test Center (RTTC). This state-of-the-art research and testing facility examines refrigeration, air conditioning, cold storage, and other thermal-based technologies in support of SCE's EE programs, customers, and industry partners. The lab features walk-in controlled-environment chambers with impressive refrigeration and heating capacity, numerous types of test equipment and tools, and the ability to perform in-house calibration of many related instruments.

Southern California Lighting Technology Center

Integrating sphere testing is conducted at the TTC's SCLTC. In partnership with the California Lighting Technology Center (CLTC) in Davis, California, SCLTC's mission is to foster the application of EE lighting and day-lighting technologies, in cooperation with the lighting industry, lighting professionals, and the design-engineering community. Unique lighting and day-lighting test equipment, EE lighting displays, a model kitchen, and flexible black-out test areas enable the evaluation and demonstration of various lighting technologies and applications.

APPENDIX B – EQUIPMENT

The following table highlights the equipment used in the testing of the LED lighting discussed in this report.

TABLE 15. LED FIELD TEST EQUIPMENT

MANUFACTURER	MODEL	CALIBRATION	DESCRIPTION	USED FOR	SPECIFICATIONS
Labsphere	SLMS LED 7650	Monthly	Spectral light measurement system (integrating sphere)	Luminous flux, correlated color temperature, color rendering index	Sphere-spectroradiometer method, 76" diameter, 4pi geometry, 350-850 nm spectroradiometer bandwidth, auxiliary compensation, D65 white point
Fluke	435	9/29/2008	Power quality analyzer	AC-side electrical logging, voltage, current, power, frequency, power factor, current THD	1-1000 V (0.1%), 0-20 kA (.5%), 40-70 Hz (.01 Hz), 1-20 MVA (1%), more specifications at www.fluke.com
LI-COR	LI-210, LI-1400	12/5/2008	Photometric Sensor, Handheld data logger	Illuminance (lux)	Absolute Calibration: ± 5% traceable to NIST, Sensitivity: Typically 30 µA per 100 klux, Linearity: Maximum deviation of 1% up to 100 klux, Stability: < ± 2% change over a 1 year period, Response Time: 10 µs, Temperature Dependence: ± 0.15% per °C maximum, Cosine Correction: Cosine corrected up to 80° angle of incidence, Azimuth: < ± 1% error over 360° at 45° elevation, more specifications at www.licor.com
Tenma	72-7675		AC power source	Supplying regulated power	Output Frequency Accuracy (45.0~500Hz): ± 0.1Hz, Output Voltage Accuracy (AC0.0~300.0V): ± 0.1%rdg+1digit, Live Voltage Regulation: ± 0.1%, Load Regulation: ± (0.5%+0.1V), Wave Distortion: 0.5%THD (Resistance Load), more specifications at www.mcmconnect.com/tenma
Onset	HOBO U30-GSM	New	Remote Monitoring System	Data logging of temperatures,	Normal operating range: -20°C to 40°C, Extended operating range: -40°C to 60°C (rechargeable

MANUFACTURER	MODEL	CALIBRATION	DESCRIPTION	USED FOR	SPECIFICATIONS
				voltage, current and power	battery impact), Sensor inputs: 5 standard expandable to 10, Data Channels: Maximum 15, Logging interval: 1 second to 18 hours, Time Accuracy: 0 to 2 seconds for the first data point and ±5 seconds per week at 25°C, more specifications at www.onsetcomp.com

REFERENCES

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http://www.sce.com/business/rates/street-area-lighting.htm

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http://www.ccontrolsys.com/downloads/Manual_WNB_Pulse.pdf

[4] California Climate Zones

http://www.energy.ca.gov/maps/building_climate_zones.html

[5] Southern California Edison: Rate Design, (Discussion of Streetlight Rates), November 5, 2009